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13. ABSTRACT (Maximum 200 words)

This report results from a contract tasking Radio Physical Research Institute (NIRFI) as follows: The contractor will investigate the use of powerful HF radars to detect coronal mass ejections from the sun.

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Final RRI report on implementation EOARD contract F61775-98-WE073 "Solar Radar Detection of Coronal Mass Ejection (CME's)".

The summer 1998 session of joint NRL (US), RRI (Russia), RAI(Ukraine) test experiments was being continued as a part of the project "The Use of High Frequency (HF) Solar Radar to Detect Coronal Mass Ejections (CMEs)", 1997-98, US Supervisor - Dr. P. Rodriguez (NRL), which has been started in 1996-97 with the same objectives which are presented in the Final Report on the project (1998).

The objects for investigation were: the Sun; with the Moon and the WIND spacecraft providing auxiliary, but important experiments.

The basic properties of the new experiments were:

1. Use of experience gained from preceding experiments ,including a knowledge of the peculiarities of:
- trans-ionospheric propagation of HF radio waves;
- interference levels at the frequency range at receiver site;
- use of multi-frequency sounding and coding techniques.

2. The tests were being planned for the season of highest elevation angles of the sun: zenith angles should be at 34 deg for Vasil'sursk, the site of the Sura transmitter.

3. The proposed tests were implemented during a period of increasing of solar activity. Therefore a probability for observing CMEs events was greater.

4. Special study of trans-ionospheric propagation of powerful HF radio waves for various geophysical conditions.

The dates of solar experiments were 10 June - 04 July, corresponding to the dates of high solar elevation. The time of sun sounding tests was planned near to local noon. A duration of sessions were 15 min, which are about equal to the radar wave round-trip propagation time from earth to sun. There were variants of taking sight to the Sun to test a possibility to receive radar returns at the SURA site.

Some sessions were planned for implement on Saturday - Sunday, when it was expected small industrial interferences.
Transmission codes were examined last summer; this season we planned to use variations, such as:
- during periods of increased solar activity - 4 bits code to be used;
- during periods of quiet sun - more complicated (7 bits or 43 bits)
codes are to be used.

This summer we have tested a new coding technique. It could be described as a quasi-linear sweeping of the transmitting frequency. Frequency sweeping was done in steps of 1 kHz in two modes: 1. 30 kHz sweeping of 1.0s bit duration (LFS-1) and 2. 10 kHz sweeping of 1.4 s bit duration (LFS-2) according to the modelled solar coronal depth and Doppler width of the expected returns.

A forecast of the 27-day solar activity was performed during May period with the SOHO data (LASCO, EIT(195)).

Before and after each transmission test, there were measurements of f0F2 values with ionospheric probing.

Sun sounding **Table 1**

Date	UT	Freq(kHz)	P(kW)	Target/Mode	foF2(MHz)	Remarks
10.06	09:06-09:21	8916&53	230 240 230	Sun1/(1.35/930)	6.3	Freq. switching; AM; code Barker; Code frame length = 4*1.35 s Total length = 930 s
11.06	09:06-09:21	8916&53	230 240 230	Sun1/(1.35/930)	-	
12.06	09:07-09:22	8916&53	200 220 230	Sun1/(1.35/930)	7.6	Start on 13:07:30
13.06	09:06-09:21	8916&53	230 230 230	Sun1/(1.35/930)	-	
14.06	09:06-09:21	8916&53	240 240 240	Sun1/(1.35/930)	6.9	
15.06	09:06-09:21	8916&53	240 240 240	Sun1/(1.35/930)	6.4	
18.06	09:07-09:22	8916&53	240 230 240	Sun4/(1.35/940)	6.4	Freq. switching; AM; 63 bit code; Bit length = 1.35 s Total length = 940 s
19.06	09:07-09:22	8916&53	240 230 240	Sun4/(1.35/940)	6.8	
20.06	09:08-09:23	8916&53	240 230 240	Sun4/(1.35/940)	6.5	
21.06	09:08-09:23	8916&53	240 240 240	Sun4/(1.35/940)	5.8	
22.06	09:08-09:23	8916&53	240 240 240	Sun4/(1.35/940)	5.7	
23.06	09:12-09:27	8916&53	240 230 240	Sun4/(1.35/940)	5.1	
25.06	09:13-09:28	8916	240 250 230	CW	5.3	optoelectronics control system lockout
26.06	09:13-09:28	8916&53	240 240 220	AM: +2-2s	4.2	
27.06	....	....	....	....	....	transmitter damaged
29.06	09:13-09:28	8916&53	240 240 230	Sun4/(1.35/940)	6.6	
30.06	09:10-09:26	8900-29	240 240 230	LFS 1(1s/930s)	6.8	LFS 1 fault
01.07	09:10-09:25	8900-29	240 230 240	LFS 1(1s/930s)	7.6	LFS 1 - linear freq. scanning with step 1 kHz, bit=1s; overall duration 930 s;
02.07	09:10-09:25	8910-19	240 230 240	LFS 2(1.4s/924s)	6.8	begin was +4s later as shown (been analysed)
03.07	09:10-09:25	8910-19	240 230 240	LFS 2(1.4s/924s)	6.7	LFS 2 - linear freq. Scanning with step 1 kHz, bit=1.4s; overall duration
04.07	09:10-09:25	8910-19	240 230 240	LFS 2(1.4s/924s)	6.6	begin was +2s later as shown (been analysed)

Auxiliary tests been implemented are:
1) reflection from the Moon, for calibration of the SURA-UTR-2 radar; and
2) transmission to the WIND spacecraft, to study fine details of ionospheric effects for the current geophysical conditions. It were conducted 7 soundings of the Moon, on the following dates.

Moon sounding **Table 2**

Date	UT	Freq(kHz)	P(kW)	Target/Mode	foF2(MHz)	Remarks
19.07	05:00-06:00	8916	- 250 -	Moon(1/5)		Pulse width =1 s and period = 5 s
20.07	06:00-07:00	8916	240 230 -	Moon(1/5)		
21.07	06:50-07:50	8916	- 250 -	-"- (1.8/5)	6.7	Pulse width =1 s and period = 5 s
22.07	07:48-12:48	8916	- 250 -	-"- (1.8/5)	6.8	
23.07	09:02-09:32	8916	240 240 -	-"- (1/5)	5.9	
24.07	10:00-10:20	8916	240 250 -	-"- (1/5)	5.8	
25.07	10:51-11:11	8916	240 240 -	-"- (1/5)	6.1	Up to 14:52:40 - CW

The experiments involving WIND have been performed on 18-23 June 1998. During that period WIND was available for SURA transmissions at the same elevation angles as was occurred for the sun in the June-July 1996 - 97 period.

WIND sounding **Table 3**

Date	UT	Freq(kHz)	P(kW)	Mode	foF2(MHz)	Remark

18.06	11:00-11:50	8925	-	-	240	CW	6.3	beam zenith angle 33 deg to the south,
19.06	11:04-11:54	8925	-	-	240	CW	6.2	polarization "ordinary".
20.06	11:10-16:00	8925	-	-	240	CW	6.2	
21.06	11:18-12:08	8925	-	-	240	CW	5.3	
22.06	11:28-12:18	8925	-	-	240	CW	5.4	
23.06	11:40-12:30	8925	-	-	240	CW	5.8	

The SURA-WIND experiments have been analyzed by RRI team for to study non-linear effects in ionosphere which could be observed during the HF radio sounding along the path "earth-spacecraft". This is of importance if a sounding wave of sufficiently high power
penetrates the ionosphere where its electric field strength is comparable to the characteristic plasma field. Special experiments were carried out using different levels of sounding wave radiation from 40 kW to 750 kW of transmitter output. As a result of these experiments we can prove that under the geophysical conditions of Summer 98 non-linear effects in the ionosphere were negligible in most cases excluding rarely occurred strongly disturbed conditions. Details of these investigations are described in the Appendix.

APPENDIX. The study of non-linear effects of trans-ionospheric transfer of a powerful HF wave in the SURA-WIND tests.

It is widely practiced to diagnose ionospheric plasma by so-called "radio astronomical technique", which is based upon observation of extraterrestrial discrete radio sources. The sounding investigation, when a ground based radio waves transmitter and on board receiver of a remote spacecraft are used, has the same peculiarities as the radio astronomical technique, when weak sounding signals are under consideration. Rated radiated power of the SURA facility could permit to give evidence of some known non-linear effects of interaction between the ionosphere and sounding wave, like a self-focusing instability in ionospheric F-region, defocusing in E-region, etc. It leads to take into account the mentioned phenomena's impact to parameters of echo-signals investigated. Some results of study on the strong HF waves trans-ionospheric propagation, which were implemented in the frame of the SURA-WIND collaboration, are presented in this report.

The experiments close by a frequency of 8.9 MHz were implemented in day times of 1997-98 summer seasons, when critical frequencies of the ionospheric F2-region varied in a range 4 to 7 MHz. The WIND spacecraft was remote at distances of 40-215 R_E (RE - the Earth radius) from the Earth towards the Sun and could be observed at zenith angles of 32-40 degrees near the spacecraft culmination point. Three identical transmitting modules of the SURA facility were used to sound the spacecraft. The time interval of every sounding lasted ca 50 min, i.e. two times more than passing time of the spacecraft across the main antenna beam, which size is $\theta_{0.5} \sim 6°$ in azimuth plane (half-power beamwidth). As a rule the CW was radiated. The effective radiation power P_{eff} was ca 19 MW for one transmitting module and ca 160 MW for co-phased operating of three transmitting modules in the facility.

The RAD-2 receiver's records show that radiation intensity fluctuates strongly (Fig.1 presents a typical record of the SURA signal intensity in 20 KHz receiver bandwidth at 8925 Mhz frequency; integration time - 20 ms; sample rate - 63 ms). Scintillation index $S4(t)$ ordinary takes a value between 0.5 and 1.5, which is the specific value for saturated scintillations. In this case the remarkable intensity increases (up to 10 dB), which are called "focusing", could be observed. Typical scintillation spectra $W(\nu,t)$ for the quasi-stationary time intervals of 2-3 min values are presented in Fig.2. The values of function $W(\nu,t)$ are normalized so that $S4(t) = \int Dn\, W(\nu,t)d\nu$.
Analysis of total data records (more than 30 sessions) shows that amplitude and duration of focusings do not depend against the power of HF sounding signal P_{eff}. The same appropriateness, as an absence of strongly marked dependence against P_{eff}, was inherent to other received radiation parameters (current scintillation index $S4(t)$, and spectra of random process investigated $W(\nu,t)$). This circumstance is illustrated in:
- Fig. 2 with the spectra $W(\nu,t)$ related to the beginning, middle and end of sounding session on July 05, 1998 (the SURA outputs P_{eff} were 0.01; 1.0; 0.01 parts of rated power in accordance);

- Fig. 3 with the signal spectra $W(n,t)$ of broad range power radiated (P_{eff} = 0.19 MW- 160 MW). Also sometimes the maximal power use was followed by a broadening of main beam and corresponding decreasing of averaged signal power level, see at Fig 1, which shows the expected intensity averaged. It should underline, that the measurements results been presented above were performed at the SURA-WIND radar facilities for typical i.e. non-disturbed geophysical conditions. But for the case of disturbances the situation will drastically change. Fig.4 shows the record of signal intensity received onboard, when three co-phased transmitters operated in the date (May 04,1998) of strong ionospheric disturbances. The current spectrum of this investigated random process is presented also. The main difference of the picture from the typical case shown in Fig.2 is an increasing of fluctuations spectral power density in area near tenths Hz, which arose in the middle and end of sounding session and which is absent in the start of the facility operating.

DISCUSSION. Modern theoretical conceptions related to the self-focusing instability in ionosphere are based upon solutions of relevant diffraction problems in regular medium (Vas'kov V.V., Gurevich A.V., *Proc. Thermal non-linear phenomena in plasma* (Rus), Appl. Phys. Inst., Gorky, 81,1979.). Nevertheless as a rule in upper ionosphere there are inhomogeneities of electron number density Ne, which types are: travelling ionospheric disturbances (TID) of scale size about dozens - hundreds of kilometers, and developed turbulence of outer scale size about several units - dozens of kilometers.
An influence of small scale irregularities (size $l \leq 1$ km) could be taken into account in the frame of Born's approximation for the case of random- inhomogeneous bulk medium. The corresponding calculations show that effective distance L_{eff}, along of which the self-focusing instability develops in a medium containing random inhomogeneities, is equal approximately:

$$\Lambda_{eff} \approx 2\Lambda_{||} \qquad (1)$$

where for to estimate $\Lambda_{||}$ magnitude, one needs take a relevant value of the inverse increment of self-focusing instability in magnetoactive ionospheric plasma:

$$\Lambda_{||} \approx \lambda/2\pi (L_{||} * 2\pi/\lambda * f/f_p * E_p/E_o)2/3 \qquad (2)$$

where $L_{||} \approx 30$êì **is the spatial scale of temperature diffusion in the ionospheric F-region along the Earth's magnetic field; Eo is the incident wave field; Ep is the plasma electric field in maximum of F2 region,** f/f_p is the ratio of operating frequency to plasma frequency in maximum of F2 region, l is the wavelength.
In the SURA-WIND experiments, if to take into account a stimulated phenomenon of defocusing HF waves in the ionospheric E-region, the ratio $(E_o/E_p)2$ varied in a broad range ~ 10 - 2 ÷ ≤ 10 - 6. Accordingly to it, the value Λ_{eff} (see, (1), (2)) varied from ~45 km to ~600 km, and even more. Therefore an effective distance, along which the self-focusing instability could be developed, as a rule it would be more than scale size (L ~ 30 km) of homogeneous atmosphere at the height of ionospheric F2 region. In other words for the SURA-WIND experiment conditions an evident self-focusing instability of HF radio waves, which to be produced by weak small scale disturbances being born in the waves diffraction in randomly inhomogeneous ionosphere, is practically impossible.
To touch on the natural inhomogeneties of ionospheric plasma having scale size $l > 1$ km, it is known that, they force a remarkable distortion of amplitudes of transported HF waves, but in outer ionosphere already. The sharp focusings been observed could be related to an influence of the great scale ionospheric inhomogeneities -TID- (l = 30 - 300 km, $(\Delta N)/N$ = 0.01- 0.03). Evidently, the effects caused by this reason have not depend on an operating regime of the SURA heating facility.

RESUME. Thus in the ordinary (non-disturbed) geophysical conditions for the SURA-WIND ground based-space borne experiments it has not been recognized any definite dependence of basic energy (normalized intensity) and statistical (current scintillation index and frequency spectra of random process studied) parameters of radiation, which was recorded at the WIND spacecraft, against the power of HF signals sounded by the SURA facility.
A comparison of the experiment results with modern knowledge of self-focusing instability phenomenon indicates: that, when the ratio sounding wave intensity to plasma field intensity $(E_o/E_p)2 \leq 10-2$, the self-focusing HF waves instability in interactions with plasma practically does not develop. The observed

scintillations could be understood satisfactorily in a frame of conventional theory radio waves propagating in the ionosphere with developed irregular structure caused by natural origin. An exception to the rule are effects of beam width broadening of the facility antenna array and corresponding decrease of received radiation averaged level, which present in use of maximal facility power. The phenomena could be explained as non-linear defocusing of HF radiation transported through the ionospheric E-region.
At the same time during the SURA-WIND experiments it has been observed the marked self-focusing instability of HF radio waves for the conditions of ionosphere strong disturbed by natural origin reasons. Consequently more detailed investigations of non-linear effects, which could arose during HF radio sounding of ionosphere in the periods of geophysical disturbances, are required.